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Modeling Climate-Change Effects on Snake Range Extents for Military Land Management

Austin Rundus, James D. Westervelt, and Jinelle H. Sperry

September 2013

Construction Engineering Research Laboratory

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Abstract

The long-term management of species at risk on military installations requires consideration of the direct and indirect effects of climate change. One of the direct effects will be change in the seasonal extents of home ranges of snakes, which can change the availability of food and their impact on prey animals. Therefore, forecasting differences in home range extents is useful for predicting changes in predator-prey relationships caused by climate change. This report describes a method for predicting home range sizes for the Eastern Indigo Snake as a function of temperature and land cover. This approach could be used in future models developed to forecast population viability of snake populations and their prey.

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Preface

This study was conducted for the Engineer Research and Development Center (ERDC) under the Center Directed Research Program, Project 8G3D07, "Integrated Modeling and Risk Analysis for the Environmental Consequences of Climate Change." The ERDC technical monitor was Dr. Todd Bridges, CEERD-EM-D.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CF), US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, William D. Meyer was Chief, CEERD-CN-N; Michelle Hanson was Chief, CEERD-CN; and Dr. Alan B. Anderson was the Technical Director for Military Ranges and Lands. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

Special appreciation is owed to Fort Stewart, GA personnel John Macey, Larry Carlile, and Ron Owens, who generously provided vector-based maps and spreadsheets pertaining to ponds on that installation. The cover photo of an Eastern Indigo Snake was obtained from the website of the Fort Stewart Directorate of Public Works, http://www.stewart.army.mil/dpw/fish/indigoaorlongDIRK2.jpg (accessed 29 August 2013).

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

1.1 Background

The Department of Defense (DoD) recognizes the need for a strategic approach to the challenges posed by global climate change, including potential impacts to missions, built infrastructure, and natural resources on DoD installations. Federal drivers, including Executive Order 13514 (2009), the Council on Environmental Quality (CEQ), and the Interagency Climate Change Adaptation Task Force, prompted DoD elements to enact policy guidance. These requirements were reflected in the 2010 Quadrennial Defense Review (QDR). In response, the Department of Defense Strategic Sustainability Performance Plan: FY 2010 (2010) defined the need to integrate climate change considerations into existing processes using robust decision-making approaches based on the best available science. In the DoD Climate Change Adaptation Roadmap (2012), the Army recognized that climate change interacts with stressors that it already considers and manages. The Office of the Assistant Secretary of the Army for Installations, Energy, and Environment (OASA(IE&E)) has the lead responsibility for integrating climate change into Army planning processes.

Changing climate will begin to affect—and in some cases is already affecting—habitat for threatened and endangered species, a factor that is relevant to the land-management mission of military installations. Climate affects predator-prey dynamics, and snakes can be important as listed species or as predators of listed species. At Fort Hood, TX, the black rat snake (*Elaphe obsoleta obsolete*) preys on endangered bird species. Home range management can be a key in maintenance of these bird populations. The Eastern Indigo Snake (*Drymarchon corais couperi*), a resident species of Fort Stewart, GA is federally listed as threatened.

The size of snake seasonal home ranges can be both directly and indirectly affected by climate, and this can affect their hunting and survival success. Therefore, the development of techniques to forecast how snake home ranges might be affected by climate change will be useful in establishing and refining management strategies to help sustain populations

1.2 Objective

The objective of this project was to develop the capability to forecast home-range extents of snake populations of interest in the management of military ranges and lands, with a focus on the Eastern Indigo Snake at Fort Stewart, GA.

1.3 Approach

In developing a model of the effects of climate variability on threatened or endangered species, it is necessary to discover thresholds at which populations can no longer survive, or growth is impacted. Variables considered in this work include annual mean temperature and rainfall, maximum winter temperature, minimum or maximum summer temperature, drought frequency, and any other climate-related parameter that could cause changes in species or population viability. For the model documented here, mean temperature and rainfall were the variables selected to examine and alter in order to find thresholds at which populations can no longer reproduce enough to stay stable. These thresholds will depend on many factors, but in the current model, the parameter of interest was home range size.

The development of this capability focused on the western half of Fort Stewart, GA, a representative US Army installation that is the home of multiple threatened or endangered species. The Endangered Species Act of 1973 made management of these species a higher priority than in the past. The Army addresses this responsibility in several ways. Many global climate change projection models predict that temperature will accelerate throughout this century. There have also been several predicted scenarios for rainfall change. Many threatened and endangered species live in isolated areas that, often, are the only suitable remaining habitats. This modeling effort focused on forecasting how home range size might be affected by changes in annual temperature patterns, with reference to the habitat size threshold necessary for eastern indigo snake population viability.

The model developed in this work was implemented using NetLogo 5.0, an open-source, spatially explicit simulation modeling environment (Wilensky 1999).

1.4 Mode of technology transfer

This model and report will be made available to interested modelers of species response to climate change. It is anticipated that this developed software will be used as a submodel within more comprehensive models of snake behavior to forecast the effect of projected climate change on the home ranges of snakes and other vertebrate species. This model also can be used by others to investigate the variability in snake ranges and seasonal migration in response to both historic and future weather patterns.

2 Fort Stewart and the Eastern Indigo Snake

2.1 Fort Stewart

Fort Stewart is the largest military installation east of the Mississippi river, covering 280,000 acres of southeast Georgia. It extends into parts of Liberty, Evans, Long, Tatnell, and Bryan Counties, and is located 42 miles southwest of Savannah (Vavrin et al. 2006). Fort Stewart is an important site for eastern indigo snakes, as it encompasses a large area of their native habitat.

2.2 Natural history of the eastern indigo snake

The eastern indigo snake (*Drymarchon corais couperi*) can grow to 265 cm, and is the longest snake native to the United States. The snake is entirely black, except for spots of red or cream on the chin and throat. It has large, smooth scales across most of its body (Moler and Park 1999). The snake was federally listed as threatened in 1978. Many factors are believed to have contributed to species decline, including habitat loss, human-caused fatalities by intentional killing and motor-vehicle encounters, and loss of tortoise burrows (used as winter shelter) through both dwindling tortoise numbers and gassing of burrows by rattlesnake hunters (US Fish and Wildlife Service 1982, Stevenson et al. 2003). Since it has a very large home range, it is more vulnerable to continued habitat loss than many species (Moler and Park 1999).

While relatively little is known about this species, there is some literature that covers movement and habitat selection. Ninety percent of the eastern indigo snakes found during the winter by Hyslop et al. (2007) were in *Gopherus polyphemus* burrows. During spring, this proportion dropped, especially for males. In the summer, they found the lowest incidence of the snakes in the burrows, and occupancy then increased in the fall. Females had a higher rate of burrow use than males, but season had a greater effect on habitat use than sex or age.

The eastern indigo snake is found almost exclusively in the southeastern United States, throughout Florida and southern Georgia. It mainly inhabits the northern Florida and southern Georgia sand hill habitats. It origi-

nally was found throughout Florida as well as the coastal plain of Georgia, Alabama, and Mississippi. The heaviest populations of this snake are found in southern Florida.

The eastern indigo snake needs multiple habitats throughout the year because it requires shelter from both summer desiccations and, especially at the northern edge of its range, winter. In winter, it is important for the eastern indigo to find shelter, mainly in gopher tortoise burrows. Since these burrows are mainly found in the xeric sand hill habitats, the snakes are found almost exclusively in those habitats in the northern part of their range during winter. There is a lack of data on lifespan of wild snakes, but in captivity, a snake lived for over 25 years (Moler and Park 1999).

Eastern indigos breed between November and April in the northern part of their range, a timeframe that may be extended in the southern portion of the range. Average clutch sizes range from 4 to 12 eggs, which are generally laid between May and August and take about 3 months to hatch. Females have the ability to store sperm, and have been reported to be able to delay fertilization up to 4 years after mating. Parthenogenesis (i.e., asexual reproduction) is possible in eastern indigos as well, with some recent research pointing to it in several cases (Moler and Park 1999).

The eastern indigo is considered to be an active forager, able to move long distances for food, which is helpful because of the snake's changing environment throughout the year (Hyslop 2007). They hunt by both patrolling for prey on the surface and by foraging through roots and small animal burrows (Stevenson et al. 2010). Eastern indigos will eat most animals that that are small enough for them to capture. The diet of an adult may include frogs, lizards, birds, mammals, fish, turtles, other snakes, and eggs. Juveniles have been found to eat mainly invertebrates (Moler and Park 1999).

Hyslop et al. (2007) found that the mean land requirement (estimated with radio telemetry) for the snakes was 41–141 hectares (ha). They also found that home-range size changed with the season, and that males had larger home ranges than the females. Home range size was found to correlate with body size. The average home range sizes of females were 126 ha, 538 ha for males. To determine these values, the minimum convex polygon method was used. Breininger et al. (2011) also used the minimum convex polygon to calculate home range sizes of the eastern indigos on the

Atlantic coast of eastern Florida. They found that the females had mean home ranges of 76 ha and that the males had mean home ranges of 202 ha. The differences in the findings of these studies may have been related to differences in study site; Hyslop et al. worked in and near Fort Stewart while Breininger et al. (2006) worked in coastal Florida. Although there is a body of research on home range, movements, and habitat preferences for the eastern indigo snake, research related to weather variability is lacking.

3 Model Description

3.1 Purpose

The objective of the model documented here was to forecast changes in home range area for the eastern indigo snake populations on Fort Stewart with respect to rainfall and/or temperature changes. As ectotherms with large home ranges, eastern indigo snakes rely heavily on preexisting shelters to avoid both desiccation and freezing (Bogert and Cowles 1947; Stevenson et al. 2003). They often do this by staying close to one or several gopher tortoise burrows in the winter, then expanding and occasionally moving their home range during the summer. The purpose of this model was to assess how home range size might be affected by climate change. The model was also intended to provide a starting point for other modeling efforts in this field by combining weather variability with hydrology and ecological models. It is hoped that this model will support more climate change risk assessments for threatened and endangered species.

3.2 State variables and scales

The model uses a weekly time step, and the patch size is 30 m square. The weekly time step allows for movement of the snakes to be mapped without distraction by the background noise of short daily movements to and from their home shelters. The patch size of 30 m also allows for the evaluation of surrounding land to identify areas most likely to be visited by a snake over the course of a week. The extent of the model is the western half of Fort Stewart. As noted in Chapter 2, the snakes tend to be highly associated with the xeric pine sand hills habitats, which hold a large number of gopher tortoise burrows (Speake et al. 1978; Diemer and Speake 1983).

The state variables of the patches are temperature, rainfall, soil moisture, and attractiveness to the species. The temperature and the rainfall are model-wide variables, and will be the same for each patch. They are set up to be controlled provided by an outside weather model or historic weather record, but the model also allows for some manipulation by the user. Soil moisture is a variable that is unique to each patch. The rainfall, patch type, and canopy cover all affect soil moisture. The patch type describes the certain vegetation and habitat type of a patch, such as xeric pine sand hill.

Habitat types are put into geographical information system (GIS) software that gives the model an output of a habitat-suitability number (between 1 and 5). This value is meshed with distance from the snake and soil moisture to determine patch attractiveness to the snake. Each patch will have its own dynamic attractiveness value, which will change with rainfall or snake movement.

Snakes are agents that are defined by location, length, sex, and age. The values for these variables are randomly generated at initialization, and do not change throughout the simulation. The location of each snake is dynamic. Each snake is initialized in a patch that has a high suitability rating. From there, it establishes a current home range. Its location and current home range can shift depending on temperature, rainfall, surrounding habitat, and a snake's own variables (age, sex, and length).

3.3 Process overview and scheduling

At each weekly time step, the following activities occur in order:

1. The weather for the week is taken from historic weather records. The user can arbitrarily increase or decrease temperatures by a fixed amount, and total rainfall can similarly be increased or decreased by a fixed percentage.
2. Soil moisture conditions are updated based on the previous soil moisture and the current weather conditions.
3. Total habitat quality required by each snake (HQ_S) is calculated based on sex, size, and air temperature.
4. Habitat quality of each patch (HQ_P) in the study area is calculated based on innate quality (related to vegetation type), soil moisture, and gopher tortoise burrow probability.
5. From the perspective of each snake, the perceived habitat quality of surrounding patches is adjusted based on distance to the patch.
6. For each snake, the smallest set of patches surrounding the snake's home base that meets the total habitat quality requirement is identified. From this result, the smallest convex polygon that encompasses the patches and calculate the area of that polygon is calculated.

3.4 Design concepts

3.4.1 Weather

The purpose of the model is to help identify at what point changes in rainfall and/or temperature might have a significant impact on the indigo snake. This model incorporates data on both temperature and rainfall patterns from 1950 through 2010. Increasing or decreasing historic rainfall by a percentage or temperature by degrees can produce different weather. The weather design is an important part of this model because the changes in weather will be the driving factor behind home range and movement changes in the snake.

3.4.2 Soil moisture and temperature

The moisture and temperature of the soil is simulated. This affects the attractiveness of each patch to the snakes. Since the Fort Stewart is relatively flat, changes in rainfall could have implications on land use patterns. Rainfall directly affects soil moisture, which in turn affects the soil temperature. Soil temperature is important for predicting snake movements, home range sizes, and changes in home range location.

3.4.3 Snake habitat quality

Eastern indigo snakes are the largest snakes in North America, and also have the largest home ranges of North American snakes (Hyslop 2007). This means that home range extent is of great importance when modeling the snakes. A snake's home range size is mostly dependent on three factors: snake size, sex, and air temperature (Hyslop et al. 2009; Speake et al. 1978). These three variables are used in combination to return a value for total snake habitat quality (HQ_S) that each individual snake requires. This HQ_S is calibrated to give the snake a home range size that reflects sizes reported in the literature.

3.4.4 Patch habitat quality

In order to satisfy the HQ_S requirements of each snake, the individual patches must also each be assigned their own HQ (called HQ_P, or patch habitat quality). Each snake's home range consists of the selected patches surrounding the snake that satisfy its HQ_S needs. The patch HQ_P will be based on multiple variables. The first is the innate quality, which depends on vegetation type and is drawn from Sperry et al. (2012). Eastern indigo

snakes tend to extend their range, and sometimes move away from their winter gopher tortoise burrows toward other shelters such as roots, stumps, logs, and other animal burrows (Hyslop 2007). In the spring and summer, they are also found in areas with higher amounts of canopy cover as well as woody understory and palm cover (Hyslop 2007). With this need for differing habitats throughout the year, vegetation is an important part of the design of this model. The probability of finding tortoise burrows in each patch is also considered. Eastern indigo snakes have been shown to be vulnerable to desiccation (Bogert and Cowles 1947, Stevenson et al. 2003). They also have been found to use wetlands much more often in summer than in the other seasons, which would suggest the use of moisture to prevent desiccation (Hyslop 2007). Soil moisture has been shown to be important to members of the family Ambystomatidae when choosing suitable habitat (Rothermel and Luhring 2005).

Once all of these variables are taken into account, each patch is assigned a HQ_P based on a calibrated formula. Then, for each individual snake, distance to the snake's home base is calculated and used to proportionately adjust the innate HQ_P. This represents the snake assigning similar attractiveness values to close, relatively poor patches and distant, relatively high-quality patches.

3.4.5 User controls

This model was designed with multiple user controls, which allows the user to ask different questions and model many scenarios. The most basic user controls are the *initialize* and *go* buttons. These initialize the model and reset it for a new session, and allow it to run until completion, respectively. It also allows users to choose the number of weeks they wish to run the simulation, which can range from 1 week to 3117 weeks (60 years). The user also controls the number of snakes involved in the simulation and the background on which the simulation is displayed. The background options are a shaded relief map, a canopy map, a eastern indigo habitat quality map, a gopher tortoise carrying capacity map, or a blank field. The user also can turn the outline of the snake's minimum convex polygon home range off. Weather patterns can be altered by changing rainfall and temperature variables, allowing the user to explore more in-depth questions about the effects of climate variability on the snakes' home range.

3.4.6 Model initialization

At initialization, graphs and data on the interface are deleted, patches are initialized, and snakes are assigned a starting position. Initialization of the weather involves the weather data being imported into the model. Each snake is then sent to a random patch with an HQ_P value of greater than 5 that also contains gopher tortoise burrows. Each snake is randomly assigned a sex. They are also randomly assigned an age, expressed in weeks, using the absolute value of a normal curve with a mean of zero and a standard deviation of 10 years old. This method is used because the snakes are thought to live about 20 years (Hyslop et al. 2009). The snakes are then assigned a length based on a formula using sex and age. Once this is done, their home range is set up. Using GIS maps, patches are assigned HQ_P values for basic indigo quality, canopy cover, gopher tortoise carrying capacity, and soils. These maps are read in and appear on the interface screen. Vector maps of streams, roads, and boundaries are displayed to provide context for the modeler. Finally, picture files of satellite and shaded relief images are read to provide optional backdrops to the model output. During model operation, various background images can be selected for display.

3.4.7 Development of input maps

3.4.7.1 Soils (vector)

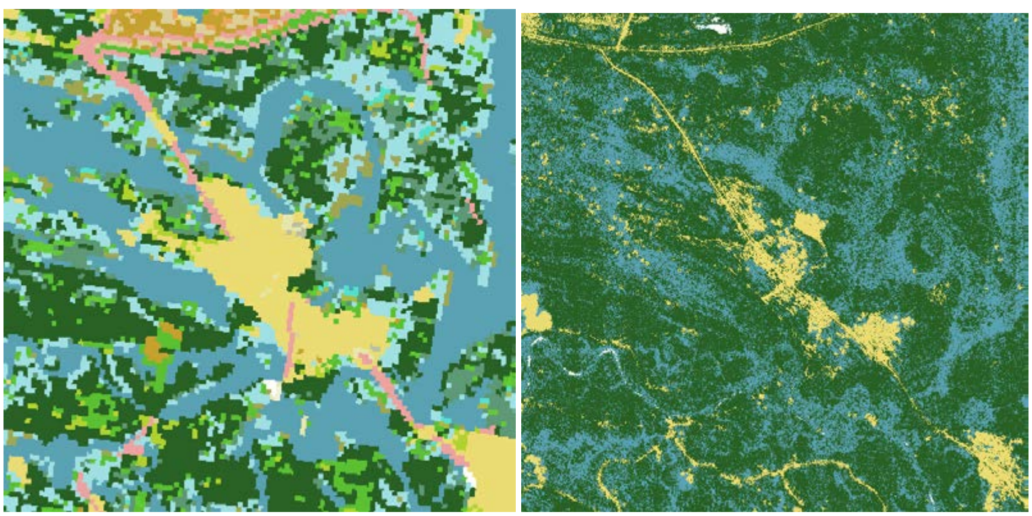
A soils map was acquired from the Fort Stewart natural resource offices, which is based on the *Soil Survey of Liberty and Long Counties, Georgia* (Soil Conservation Service 1982). The model uses the values for wilting point (i.e., the moisture content of the soil at which point leaves begin to wilt), saturation, and soil depth, which are associated with each soil polygon.

3.4.7.2 Indigo quality (raster)

The basic indigo snake quality map was developed by Sperry et al. (2012) to support the analysis of potential connections of indigo snake habitat on and off Fort Stewart. This map is based on the assignment of habitat suitability scores to land-cover categories from the 1992 *National Land Cover Database* (NLCD). Assigned scores were based on a subjective estimation of the value of each land-cover category. This map was created at a resolution of 30 m, but 5 m resolution based on more recent data is needed. This map was created using 2008 orthoimagery for Savannah, GA, obtained

from the US Geological Survey (USGS; http://seamless.usgs.gov). A sample area is shown in the left panel of Figure 1. This data was processed using software techniques to minimize the differences in color of vegetation on the sunward and shadow sides of vegetation, and was then run through the GRASS GIS image processing programs i.cluster and i.maxliks to establish a number of distinct spectral signatures and locations associated with those signatures. Each signature was then correlated with the land-cover classifications in the NLCD (1992) map and reclassified with the 1992 NLCD class that was most-represented in each of the new classes. The resulting land-cover map was then reclassified using the same indigo snake habitat suitability index developed by Sperry et al. (2012). This created a high-resolution indigo snake habitat suitability map (right panel of Figure 1).

Figure 1. 30 m 1992 NLCD map (left) and 0.5 m land cover map incorporating 2008 high-altitude image data (right).



Note: Dark green represents evergreen or managed pine, dark blue represents floodplain forest, yellow represents bare and dirt roads.

3.4.7.3 Tortoise potential density (raster)

Because indigo snakes are dependent on gopher tortoise burrows, the model depends on gopher tortoise densities. This model adopts a gopher tortoise carrying capacity map developed by Tuberville et al. (2012) that incorporated soil-type and canopy-cover data.

3.4.7.4 Background maps (vector)

Vector-based stream, road, and boundary maps provided by Fort Stewart are used as map backdrop information to provide viewers with reference

points. Additionally, a shaded-relief image based on a 5 m resolution digital elevation model (DEM) is also available to include useful background context. The DEM was created by processing LiDAR (Light-based Detection and Ranging) data that was also provided by Fort Stewart.

3.4.8 Submodels

3.4.8.1 Weather

The weather submodel starts with a file that compiles 60 years of Fort Stewart weather data, starting in 1950. It delivers temperature and rainfall data at a weekly interval. It imports the minimum, maximum, and mean temperatures as well as weekly rainfall and maximum daily rainfall. The program then generates a list with the data, but only keeps the week, year, mean temperature, and weekly rainfall, setting everything else to zero. The user can set the number of weeks of data to read in with a slider control on the user interface; this controls the length of the simulation. The interface also allows control of the climate so the user can test different levels of climate variability.

3.4.8.2 Soil moisture

Soil moisture is calculated in a soil-hydro submodel at each time step. It is based on the Century Soil Organic Matter Model, originally developed at Colorado State University (Dyck 1983, Brouwer and Heibloem 1986, Schwab et al. 1993). It starts by setting the potential evapotranspiration rate as a function of the week of the year and the temperature. It then sets the actual evapotranspiration rate as a function of the proportion of soil moisture to the maximum possible soil moisture (i.e., saturation point). It also uses the wilting point. The soil depth is then set at 0.6 meters, because the Century model uses four 15 cm layers. The soil moisture is recalculated at each time step as a function of wilting point, the soil moisture from the previous week, and the rainfall for the week. Also involved are the evapotranspiration rate, soil depth, and percentage of the saturation point. If the calculated soil moisture is greater than the actual saturation point of the soil, then it is set to the saturation point.

3.4.8.3 Snake habitat requirements

At each time step, a habitat requirement value ($HQ_{S)}$ for each snake is calculated using Equation 1. The mean weekly temperature is calculated from the daily weather input into the model, and is considered along with the

size of the snake for a new weekly HQ_S rating. (This value is later compared with the habitat quality (HQ_P) of the surrounding patches to establish current home ranges to satisfy the current HQ_S .) The HQ_S algorithm is

$$HQ_S = a \times (T - nt) + b \times M_S + c \qquad \text{Equation 1}$$

where

HQ_S = Snake habitat quality requirement
a = Temperature factor
T = Temperature (Celsius)
nt = Nominal temperature
b = Snake mass factor
M_S = Snake mass (g)

3.4.8.4 Patch habitat quality

At each step, each patch has its own unique patch habitat quality, or HQ_P. It is a function of the innate patch habitat quality (IHQ_P) and adjustments associated with tortoise presence and current soil moisture (Equation 2):

$$HQ_P = IHQ_P + e \times (SM_P - nsm) + f \qquad \text{Equation 2}$$

where

HQ_P = Patch habitat quality
IHQ_P = Patch innate snake habitat quality
e = Soil moisture factor
SM_P = Patch soil moisture
nsm = Nominal soil moisture
f = Soil moisture constant

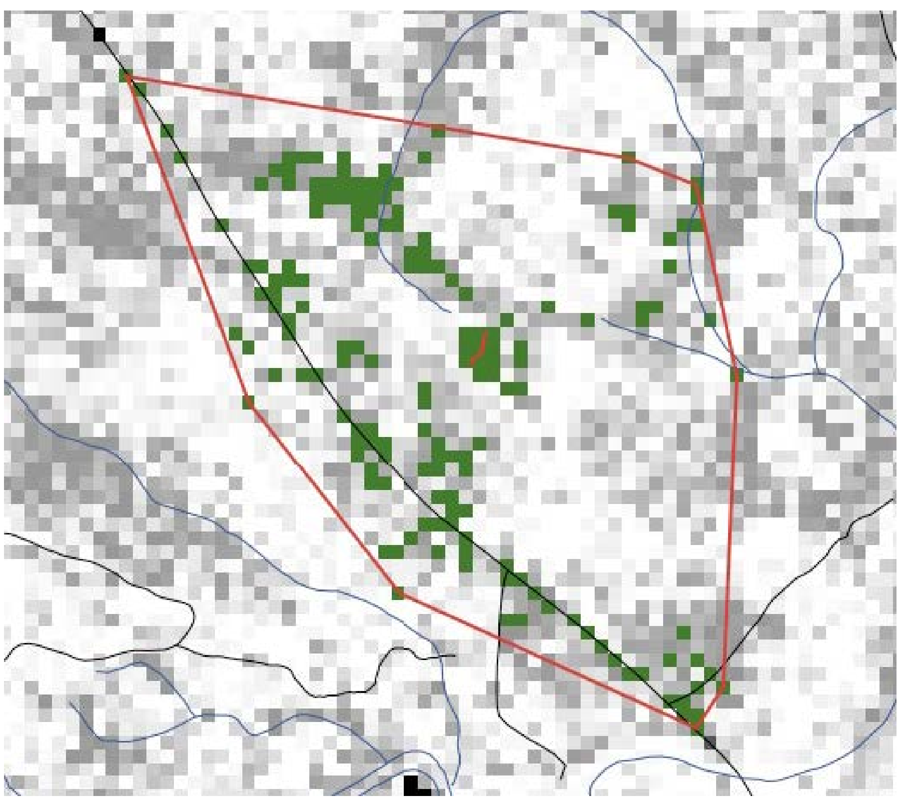
Through this regression equation, HQ_P (an index value provided via a pregenerated raster map based on land cover) is adjusted based on patch soil moisture.

3.4.8.5 Home ranges

With the computation of the value of each snake total habitat quality (HQ_S) value and patch quality (HQ_P) requirements, snakes can proceed to

establish a home range. Each snake considers the nearby patches, decreasing their values based on distance. Nearby low-value patches can be more valuable to an individual snake than more-distant high-value patches. With the individualized value of nearby patches set, those patches are accordingly rank-ordered. The associated snake then establishes the most-valuable patch as part of its home range and proceeds down the list until the total value of the selected patches meets or exceeds the required total habitat value. Once the HQ_S is satisfied, a minimum convex polygon using the patches is calculated, and the area can be reported and compared with published values. A sample result is shown in Figure 2. The green patches have been selected by a single snake as the optimal set of patches to regularly visit. The current overall value of patches to indigos is represented by greyscale values of white (worst) to black (best). The red outline is the calculated minimum convex polygon that contains all of the chosen patches.

Figure 2. Home-range selection.



The grayscale background (white is worst) represents the current quality of habitat. Green patches have been selected by the snake (in the middle). The minimum convex polygon is displayed in red.

This submodel was designed to help investigate how climate-change-induced alterations in temperature and rainfall patterns might affect the home range sizes of Eastern Indigo Snakes, including the question of whether there are temperature or rainfall thresholds that might inhibit

movement and dispersal of the snakes. Experiments that could be run include identifying how changes in home-range size might respond to seasonal changes in rainfall and temperature.

The formula in this submodel (Equations 1 and 2, above) are ready for calibration to calculate habitat quality required by snakes (HQ_S) and provided by patches (HQ_P).

3.5 User interface

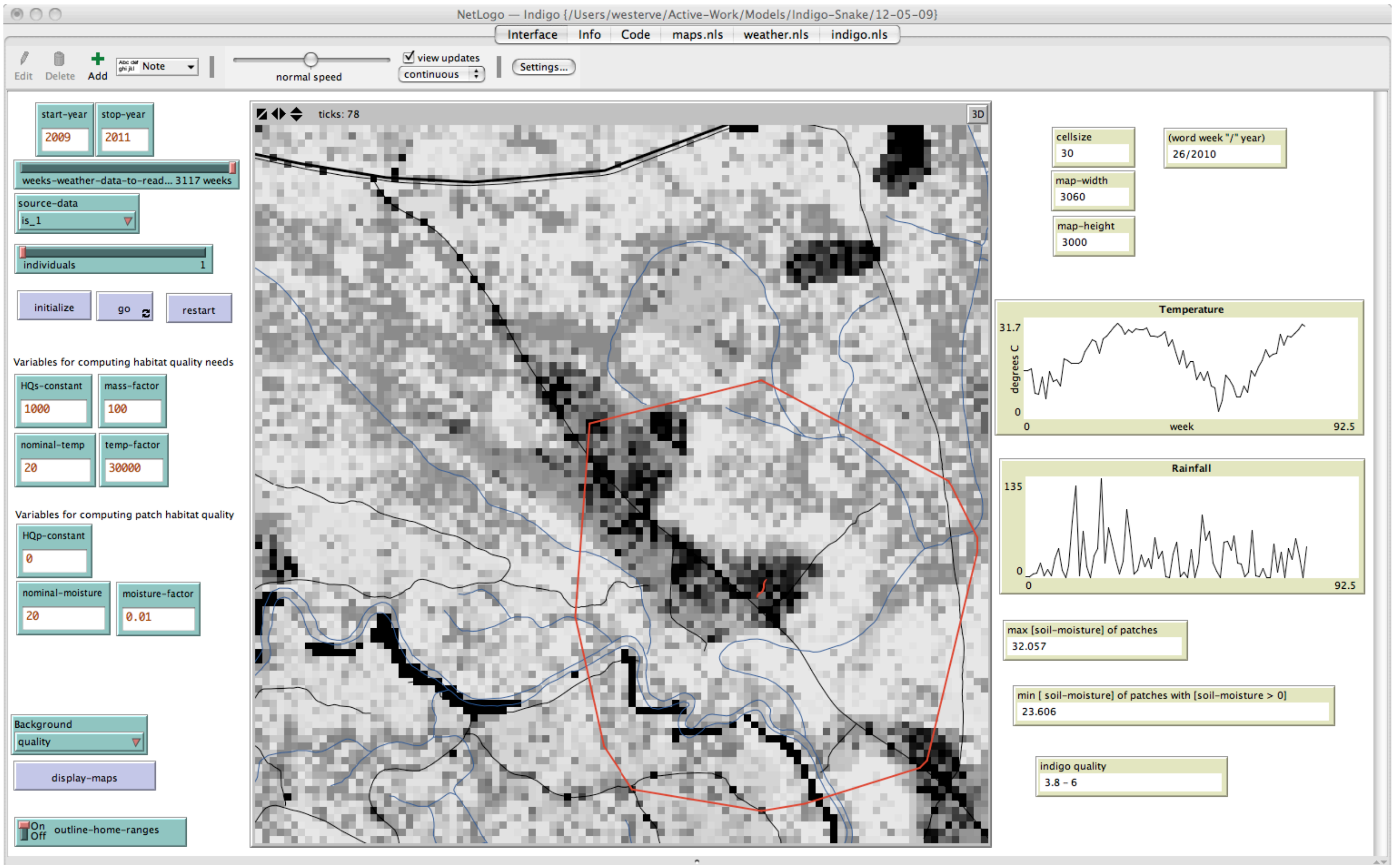
A sample of the user interface is displayed in Figure 3. It uses many of the standard NetLogo graphical user interface elements (Wilensky 1999). The three purple-tinted buttons grouped on the left allow for initialization, running, and restarting of the model. Above those are settings that must be established before model initialization, including start and stop years, the amount of the weather file to read in, the study area to use, and the number of individual snakes to establish at initialization. The variables below the three control buttons are those used to calculate habitat quality required by snakes (HQ_S) and provided by patches (HQ_P). Below that is a dropdown menu that allows the user to select the information to be displayed as a background. These include no image, satellite image, shaded relief, canopy, base quality, patch quality, gopher tortoise carrying capacity (gt-cc, which correlates with tortoise burrow availability), wilting point, saturation point, soil depth, and soil moisture. At the bottom left is a switch that turns display of home-range outlines on or off. To the right of the map are several model output displays. Those at the top-right indicate the total width and height of the map in terms of patches, and the size of each patch in meters, along with the current model week and year. The two graphs indicate the weekly rainfall and temperature over a model run.

The map image in the middle is a snapshot of the state of a sample study area showing the IHQ_P values (see section 3.4.8.4) of each patch represented as grayscale values, ranging from white (very low indigo quality) to black (very high indigo quality).

The darker area taking up most of the center is a gopher tortoise management area, which shows a lot of high habitat quality for the indigo snake. The red outline shows the result of placing a snake of a given size, with an associated HQ_S, at a specific home location in the simulation space. That simulated snake has evaluated the range and adjusted the quality, based on distance, to create individualized HQ_P values for the surrounding

patches. The red outline indicates the minimal set of patches selected by the snake that satisfies its habitat needs. It is the the minimum convex polygon established by the model that surrounds the individual snake's chosen patches.

Figure 3. Indigo snake model interface.



4 Conclusions

The home range size of the federally threatened Eastern Indigo Snake changes in response to environmental factors, including temperature, humidity, wind speed, amount of direct sunlight exposure, and land cover. Range size is related to an individual snake's body mass.

Based on many of these factors, we developed spatially explicit modeling approach and software for forecasting a snake's home range. Instead of treating a snake as an independent agent that moves through its environment, our approach identifies the habitat quality requirements of each snake and the habitat quality of each patch of land on a gridded landscape. For a given snake, the patch quality is a function of the vegetation type and the distance from the snake's home base. Our model then identifies the minimum number of patches that provide the snake with its required combined quality. A minimal convex bounding box is then automatically calculated for the snake's required set of patches to establish the traditional definition of a home range.

The formulas in the model are validated and ready for calibration, and the model is now available to interested scientists for exploring changes in Eastern Indigo Snake home range based on projected climate change. The home ranges can be calibrated with respect to specific field studies as a function of weather and time of year.

Continued and accelerated climate change will impose significant direct and indirect changes on ecosystems, affecting species of concern that DoD is responsible for managing on military installations. The ability to forecast home-range extents will be necessary to understand and predict the impact of climate on the success of endangered snake populations and other endangered species populations preyed upon by snakes.

Abbreviations and Acronyms

Term	Definition
a	Temperature factor
b	Snake mass factor
e	Soil moisture factor
f	Soil moisture constant
GT	Gopher Tortoise
ha	Hectare
HQ_P	Patch habitat quality
HQ_S	Snake required habitat quality
IHQ_P	Patch innate snake habitat quality
M_S	Snake mass
nsm	Nominal soil moisture
nt	Nominal temperature
SM_P	Patch soil moisture
T	Temperature (Celsius)

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The long-term management of species at risk on military installations requires consideration of the direct and indirect effects of climate change. One of the direct effects will be change in the seasonal extents of home ranges of snakes, which can change the availability of food and their impact on prey animals. Therefore, forecasting differences in home range extents is useful for predicting changes in predator-prey relationships caused by climate change. This document describes a method for predicting home range sizes for the Eastern Indigo Snake, as a function of temperature and land cover. This approach could be used in future models developed to forecast population viability of snake populations and their prey.

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